TPF Terrestrial Planet Finder

# Design and Fabrication of High Precision Masks for TPF Coronagraph

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**Exo-Planet Science & Technology Fair**
**Jet Propulsion Lab**
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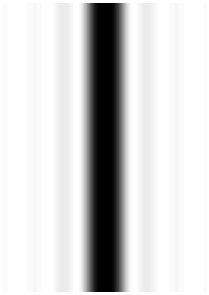
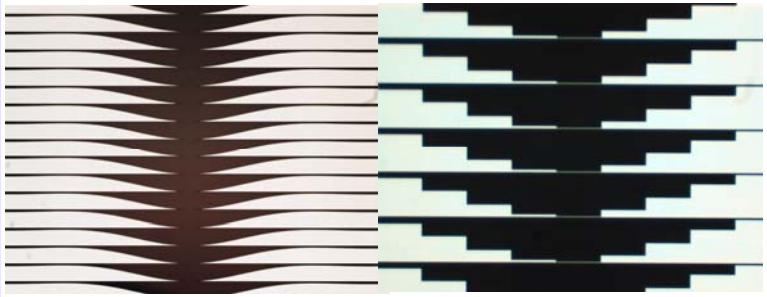
# Objectives

- Technology Development and Maturation
  - High Energy e-beam Writing
  - Patterning and Microlithography
  - Deep Reactive Ion Etching
  - Profiled Deposition
- Design, Fabricate, Characterize and Test various masks
  - Image Plane Masks
  - Shaped Pupil Masks
  - Vortex Masks
- Demonstrate performance in laboratory test beds
  - HCIT Tests

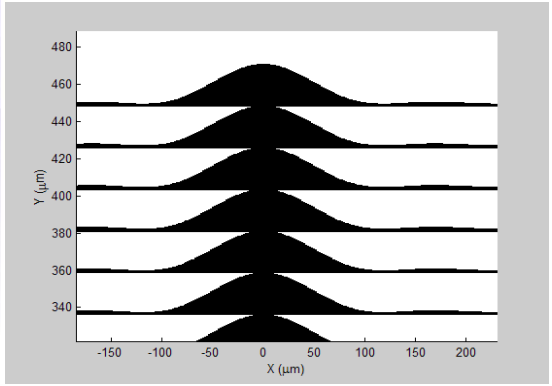
# Gray Scale and Binary "Band-limited" Masks



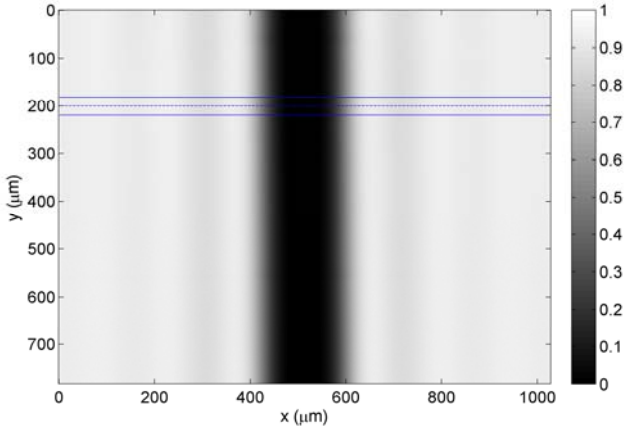
**Conceptual transmission images of the inner region of (a) one- and (b) two-dimensional gray scale 1-sinc$^2$ type "band-limited" masks**



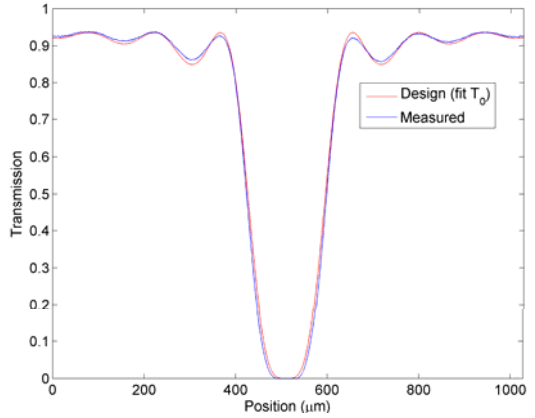
**Examples of continuous binary mask and sampled binary mask fabricated and tested at JPL**




**Close-up view of one dimensional binary 1-sinc$^2$ type mask pattern; black areas are made of perfectly opaque and etched metal layer**

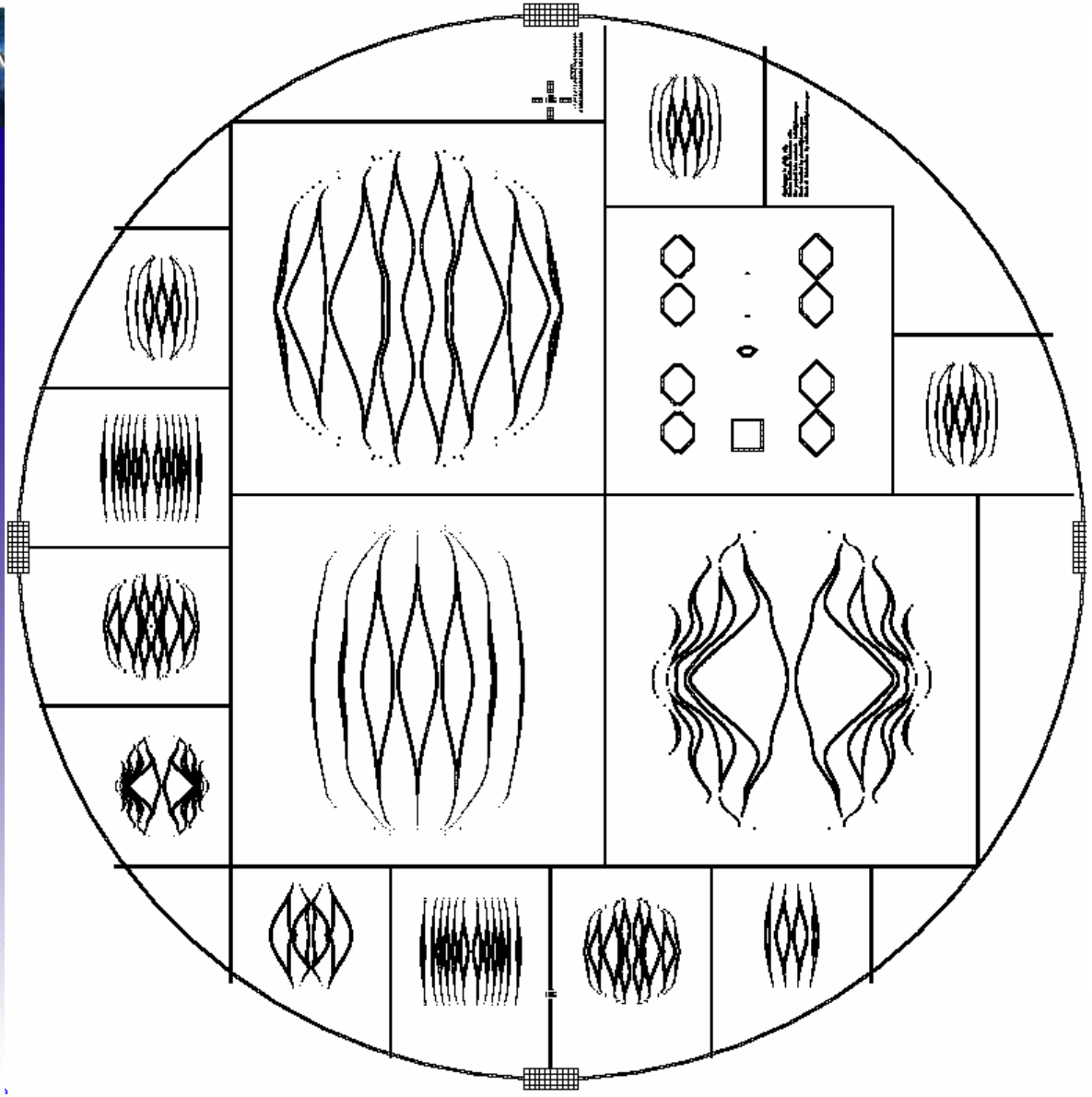



**Measured intensity-transmission image of a 1-sinc$^2$ type one-dimensional gray scale mask fabricated on HEBS glass at JPL. Lines indicate the region of profile averaging for cross-section data shown in figure below.**




**Cross-section profile of 1-sinc$^2$ mask (50-row average between lines in top figure. A fit of the design function $T(x) = T_0[1 - \text{sinc}^2(x/w)]^2$ with maximum transmittance $T_0 = 0.935$ as a parameter is shown for comparison**

# Shaped Pupil Masks
## Princeton Designs



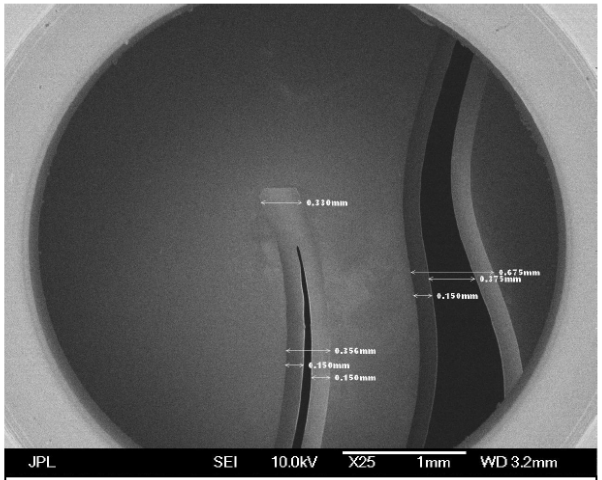



Figure 4. Typical shape and image of apertures of an actual mask fabricated by DRIE technique

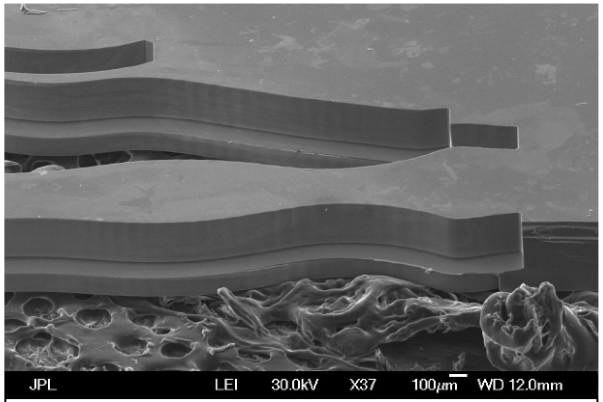



Figure 5. A mask slit seen under SEM showing recessed steps surrounding the slits

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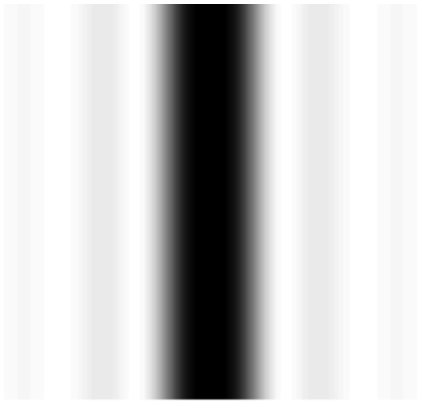
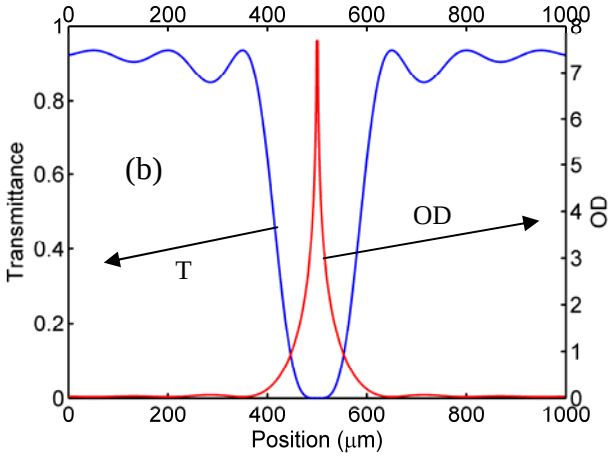
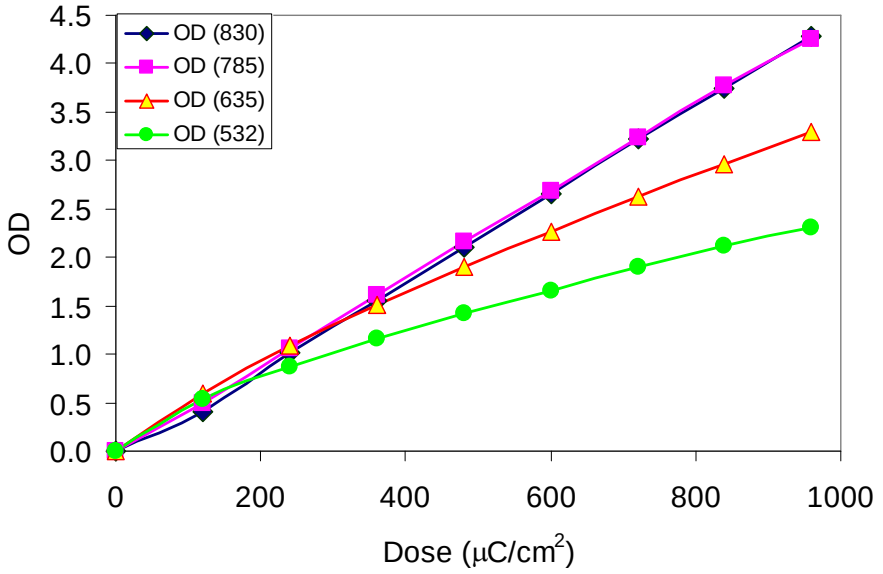
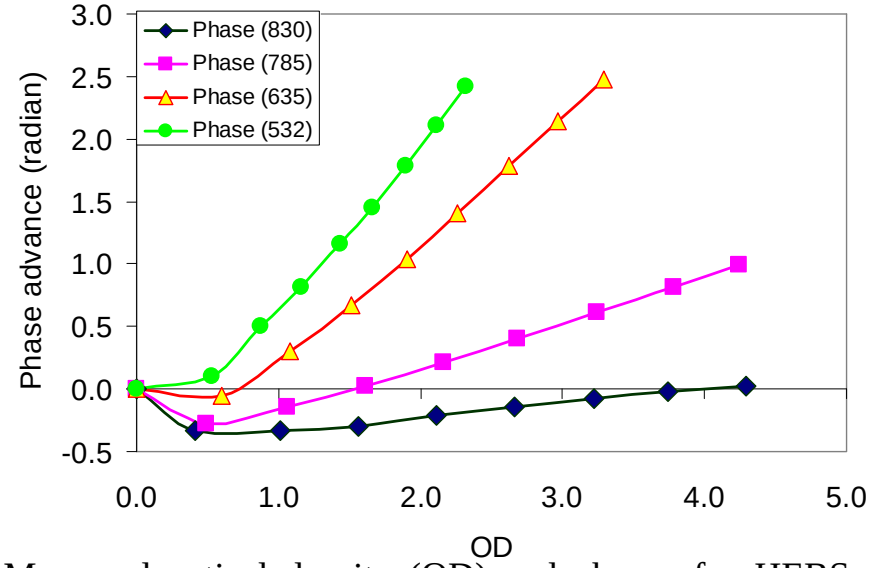
# HEBS Glass Image Plane Masks






A typical 1-dimensional gray scale mask transmission image (a) and cross- section transmittance and OD profiles (b).
Such masks are fabricated with electron beam writing technique at JPL



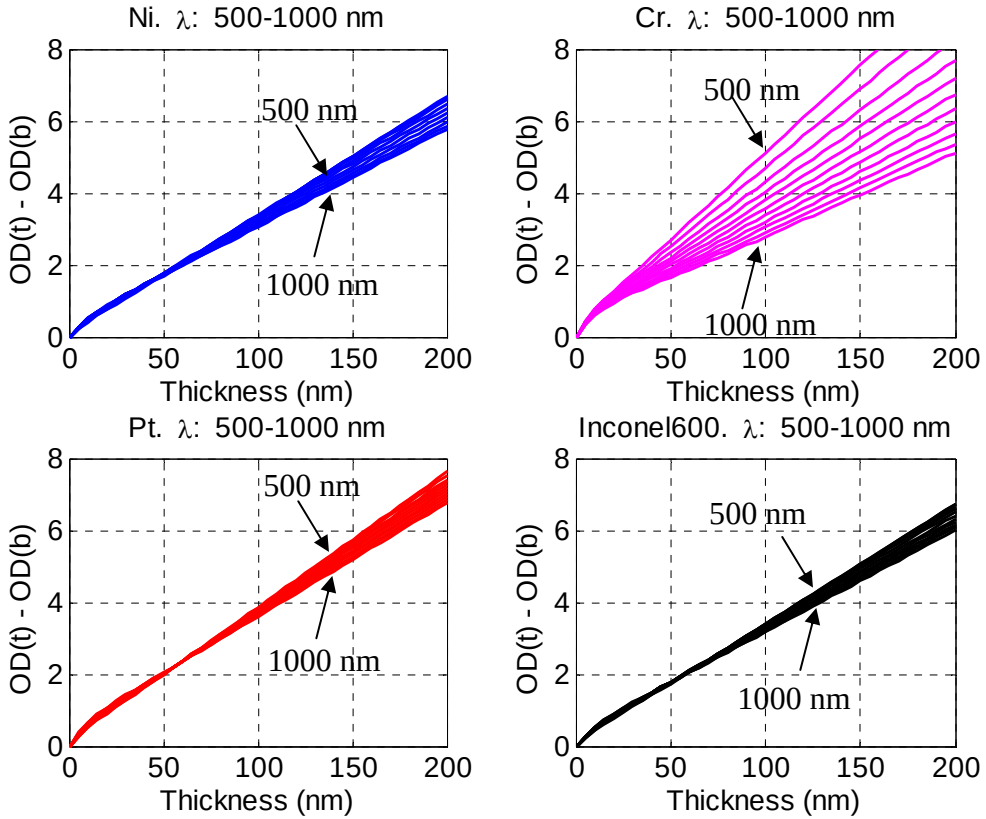

Measured optical density (OD) and phase of a HEBS glass material which shows a large variation with wavelength

**Appl. Optics, Jan (2008), pp. 116-125**

# Alternative Mask Materials



## Candidate Materials for Profiled Metallic Masks
## Low Dispersion Ni, Pt and Inconel vs. High Dispersion Cr

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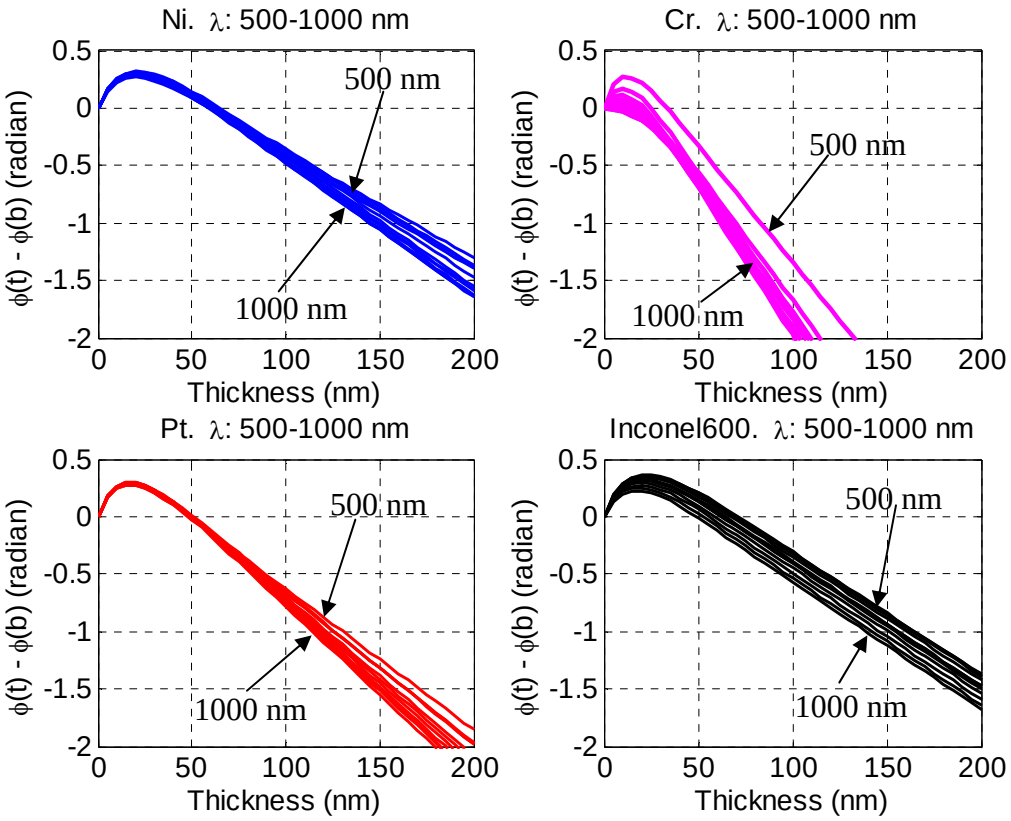
# Phase Dispersion

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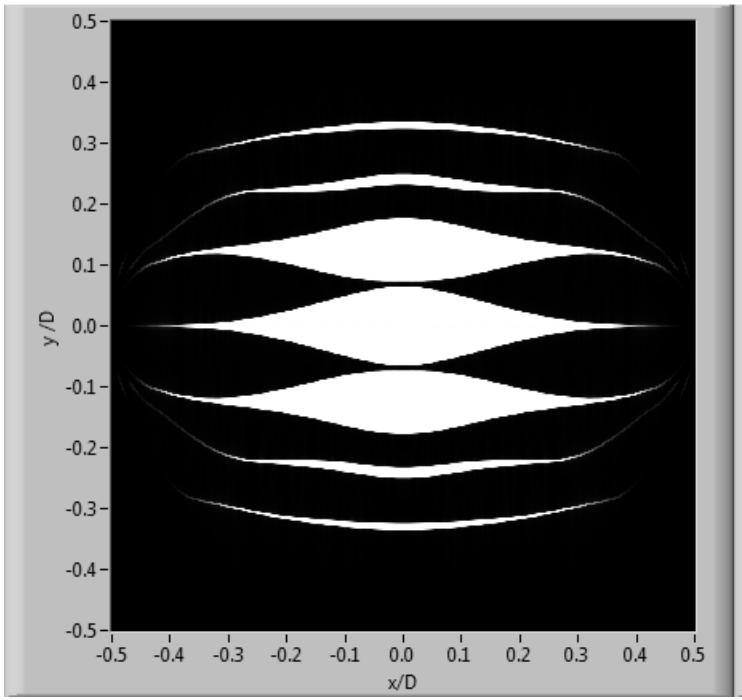
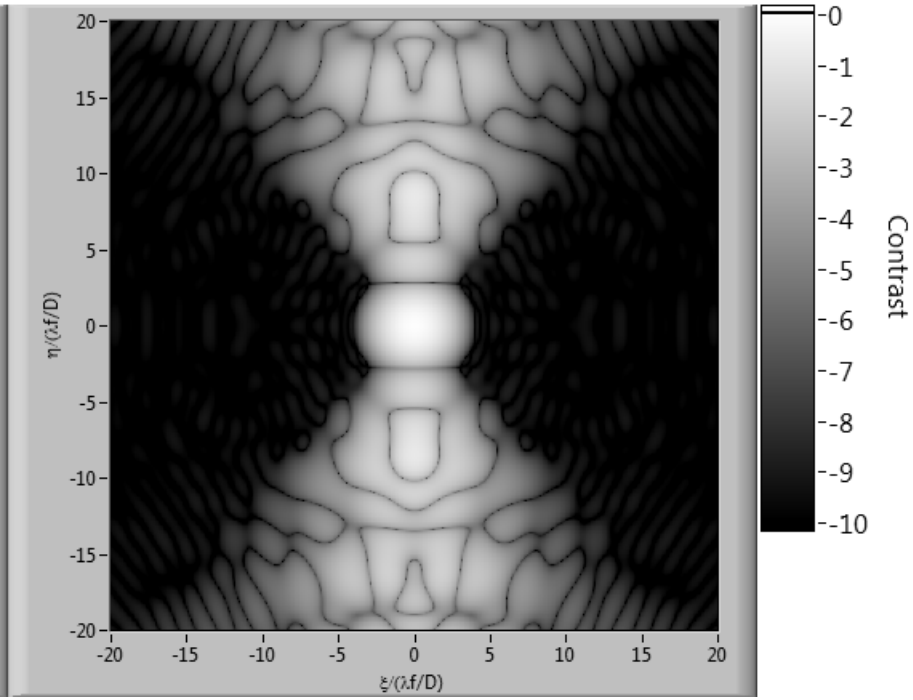
# Ripple3 Shaped Pupil Mask and PSF High Contrast Dark Zones




Shaped Pupil Mask fabricated at JPL employing Deep Reactive Ion Etching Technique




PSF and dark zones obtained with this mask

Ref: Belikov et al., SPIE 6693-36 (2007)

# Key Results

- Image plane masks employing High Energy Beam Sensitive (HEBS) glass have been fabricated successfully at JPL.
- With HEBS image masks, coronagraph contrast of ~$2.5 \times 10^{-10}$ has been demonstrated with monochromatic light in the JPL High Contrast Imaging Testbed (HCIT).
- More recently, ~$2 \times 10^{-9}$ contrast has been achieved in10% broadband light with a metallic mask.
- Also, free-standing shaped pupil masks designed by Princeton University have been fabricated successfully at JPL; a record contrast of $2.4 \times 10^{-9}$ with 10% broadband light has been demonstrated (Belikov et al) with such a shaped pupil mask.

# Summary

- Significant advancements have been accomplished in the design and fabrication of masks
- Further work in progress to develop better masks for broadband performance

**Publications**


- **K. Balasubramanian, Band limited image plane masks for Terrestrial Planet Finder Coronagraph: materials and designs for broadband performance, Appl. Optics, Jan (2008), pp. 116-125**
- **K. Balasubramanian, E. Sidick, D.W. Wilson, D. J. Hoppe, S. B. Shaklan, J. T. Trauger., "Band-limited masks for TPF coronagraph", C.R. Physique, 8, (2007), 288-297, doi:10.1016/j.crhy.2007.03.001**
- **K. Balasubramanian, D. J. Hoppe, P. G. Halverson, D. W. Wilson, P. M. Echternach, F. Shi, A. E. Lowman, A. F. Niessner, J. T. Trauger, and S. B. Shaklan., "Occulting Focal Plane Masks for Terrestrial Planet Finder Coronagraph – Design, Fabrication, Simulations and Test Results", Proc. of IAU Colloquium 200, Direct Imaging of Exo-Planets, Cambridge University Press, (2006) pp. 405-409.**
- **Ruslan Belikov, Amir Give'on, Brian Kern, Eric Cady, Michael Carr, Stuart Shaklan, Kunjithapatham Balasubramanian, Victor White, Pierre Echternach, Matt Dickie, John Trauger, Andreas Kuhnert, N. Jeremy Kasdin, Demonstration of High Contrast in 10% Broadband Light with the Shaped Pupil Coronagraph, Proc. SPIE 6693-36 (2007)**

# Acknowledgements

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